

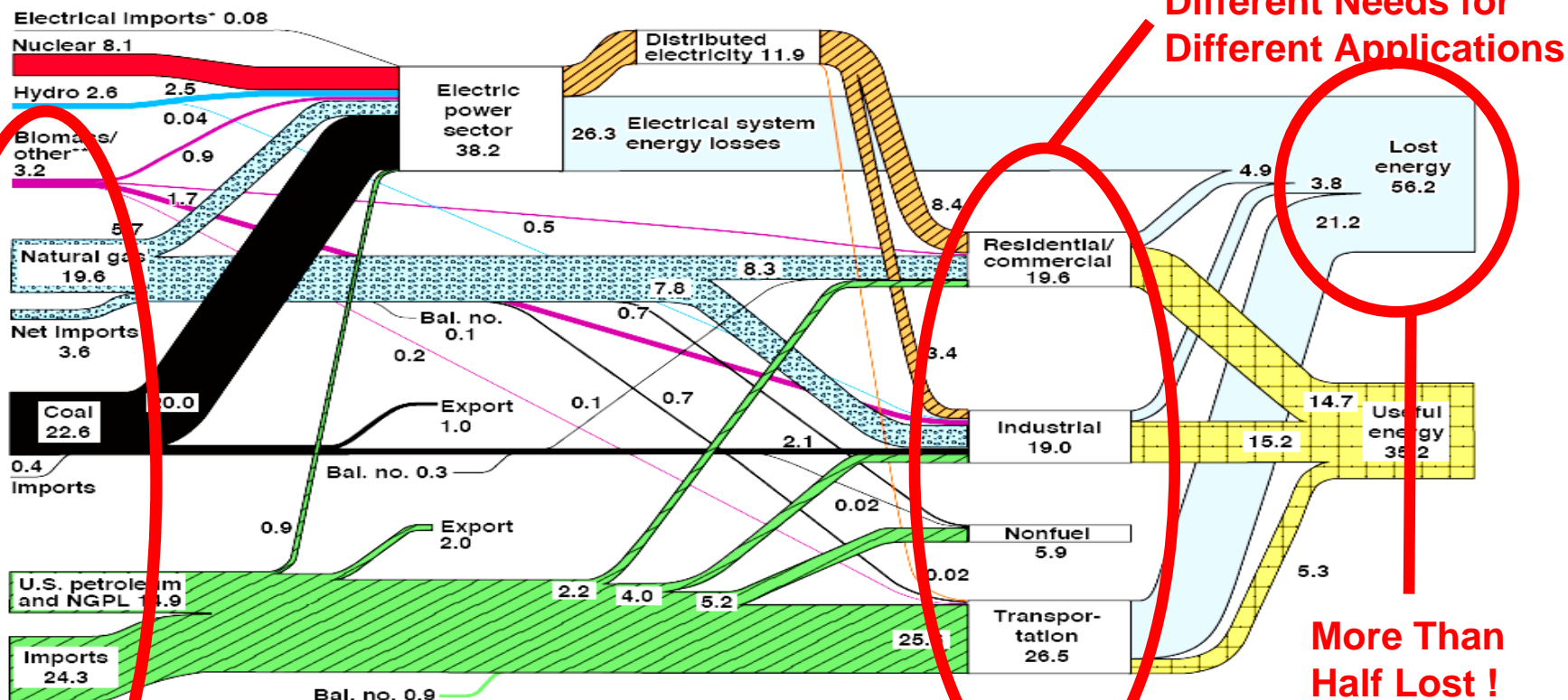
Carbon Management: Opportunities for Future Energy Systems



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What "Type" of Energy Must We Have?



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.

*Net fossil-fuel electrical imports.

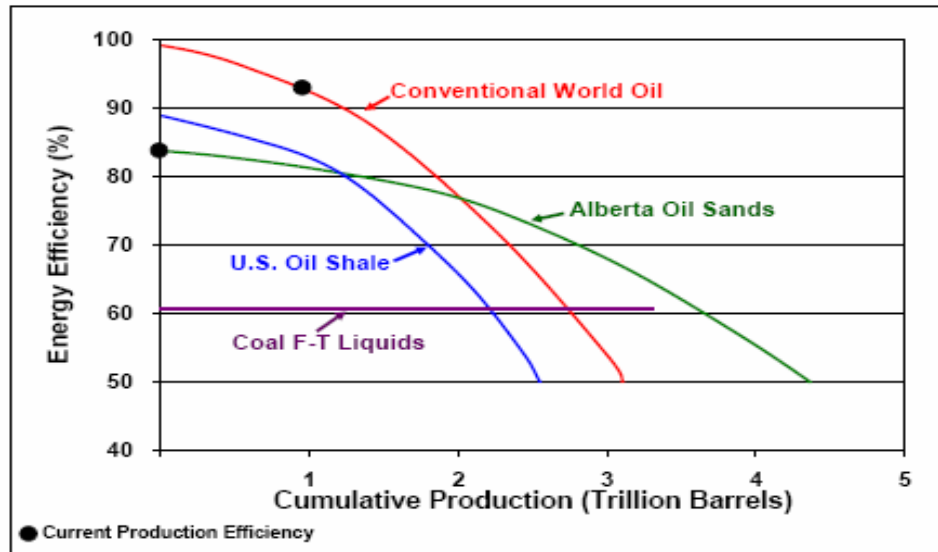
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
Lawrence Livermore
National Laboratory
<http://eed.llnl.gov/flow>

Production Efficiency and Flexibility are Key

Carbon

It Takes Energy to Produce Energy



Energy Efficiency vs.
Cumulative Production – The
Example of Hydrocarbons
(Source: US DOE Fossil Energy)

- **Opportunity**
- **Optimize Efficiency of Energy Production and Use**
- **Hybrid Energy Systems to Manage the Carbon Cycle**
 - Design energy production systems to capture benefits of individual energy sources / carbon sources
 - Optimize end product cost/stability of supply, environmental impact, and security



Managing the Carbon Cycle – An Example

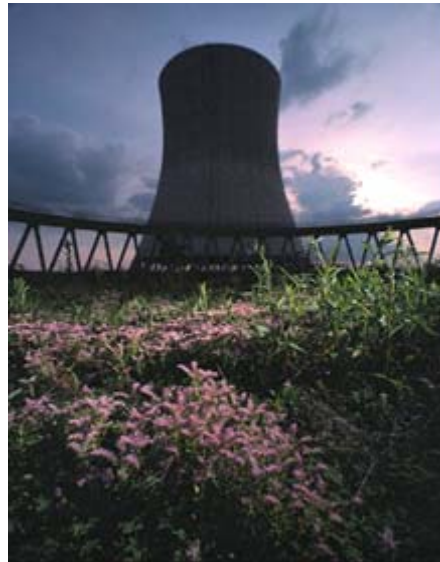
- **A hybrid system**

- Fossil, Nuclear, Biomass Nexus

- **Liquid fuels production**

- **Baseline for comparison**

- “Standard” F-T process
- More than double CO₂ emitted vs. oil derived baseline

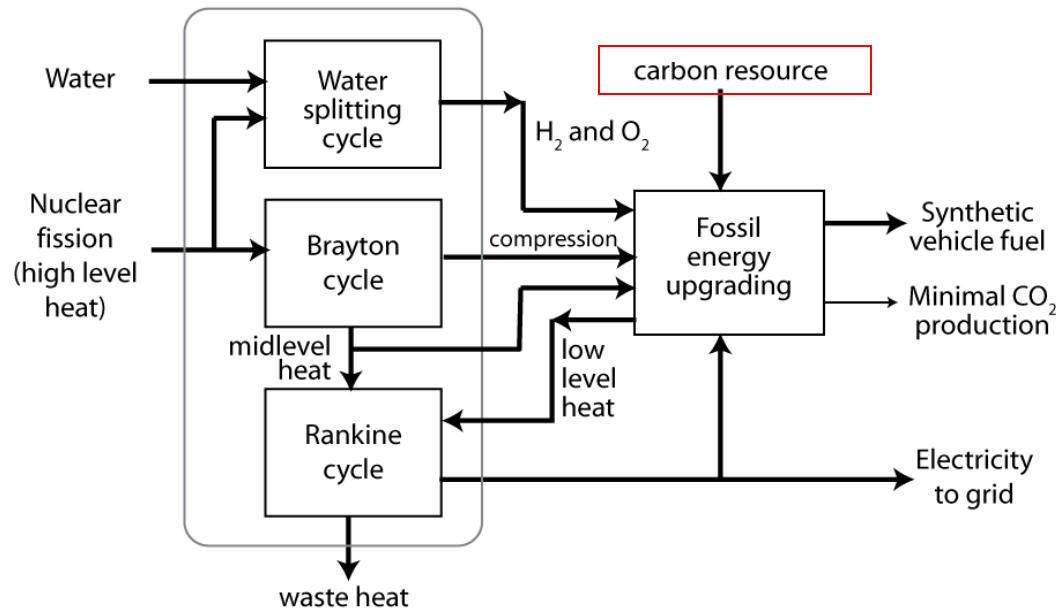


Sources:

- General Atomics Study
- INL Study: Dr. Richard Boardman,
- INL Study: Dr. Robert Cherry

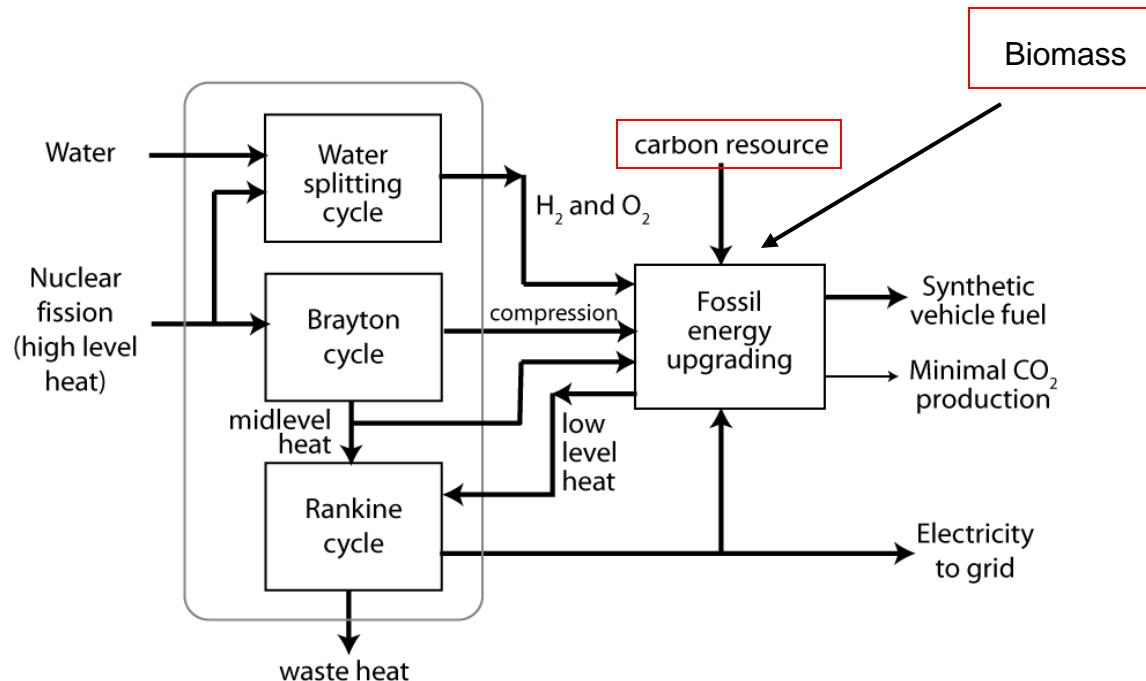
Hybrid Process Example #1

- Hybrid process #1: Low-carbon resource to produce H_2 instead of coal
 - On-par CO_2 emissions with oil-derived baseline



Hybrid Process Example #2

- **Hybrid process #2: Low-carbon energy and co-fire biomass with coal (or add recycled CO₂)**
 - Net CO₂ decrement compared to oil derived baseline

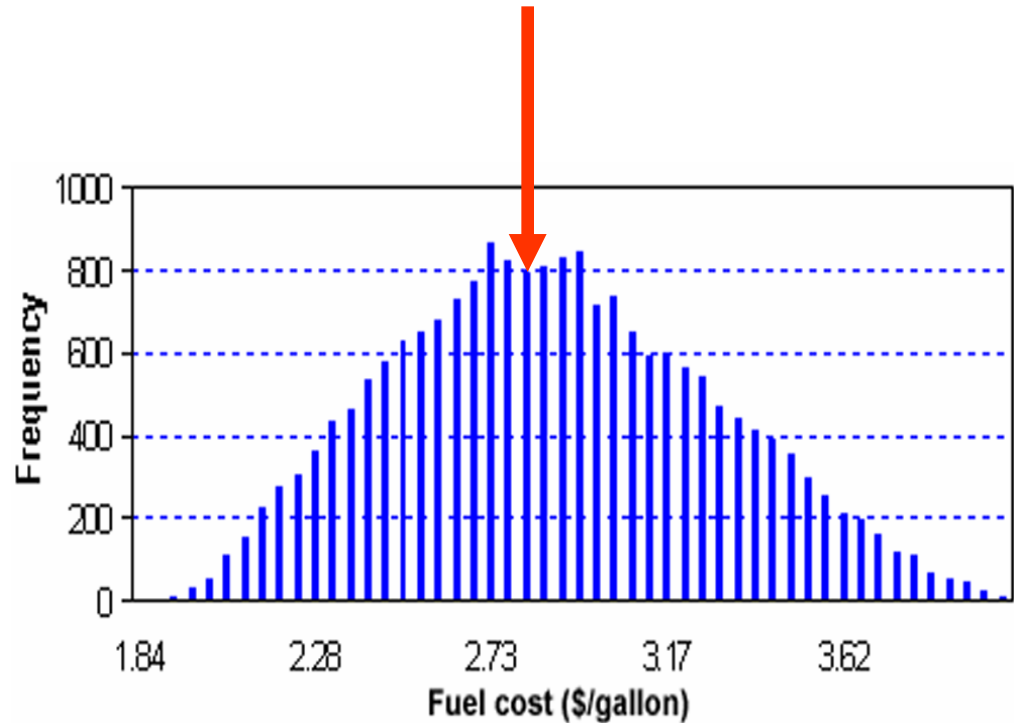




Pie in the Sky?

INPUT VARIABLE	RANGE
Stream factor	85 - 95%
Coal cost	15 - 35 \$/ton
CO ₂ penalty	0 - 100 \$/ton
Electricity value	2 - 6 cent/kWh
Oxygen value	0 - 40 \$/ton
HTGR cap. cost	700-1300 \$/kW _{th}
O&M & ins. - coal	5 – 9 % of cap.
O&M & ins. - nuc	5 – 9 % of cap.
Pretax simple ROI	18 - 24 %

Expensive – But Not Unrealistic



Conventional CTL was \$1.87/gal on a comparable basis



Consider Carbon Efficiency

	Baseline Non-Nuclear CTL Plant	CTL Plant with Nuclear Integration	CTL Plant with Recycle & Nuclear Integration	Smaller CTL Plant with Recycle & Nuclear Integration
Coal Feed (ton/day)	18,800	18,800	18,800	5,800
Liquid Fuel Produced (bbl/day)	26,000	58,200	84,672	26,000
Conversion (bbl liquids per ton coal)	1.38	3.09	4.49	4.49
Yield of Liquid Fuel (% of carbon input)	29.5	65.8	95.7	95.7

Benefits

- Much improved carbon intensity
- Extend energy resources with simultaneous high-value product
- Energy Security



A Scarcity of Technology & Talent – Not Energy Resources

- **Good News: Abundance of primary energy**
- **Hybrid systems tap inherent attributes of each energy source, creating more fungible energy assets**
- **Carbon Management**
 - High-value energy products
 - Optimize carbon intensity, security, economic considerations together
 - Legacy retrofit and strategically planning new

A satellite image of the Earth at night, showing the continents of North America, Europe, and Africa. The landmasses are covered with a dense pattern of yellow and white lights, representing city lights and urban areas. The oceans are dark blue.

**Our Challenge:
*Smarter Energy Systems***



Do Not Count on the Market Alone.....

“Pure market economics will never solve this (oil) problem.

Markets do not account for the hidden and indirect costs of oil dependence.

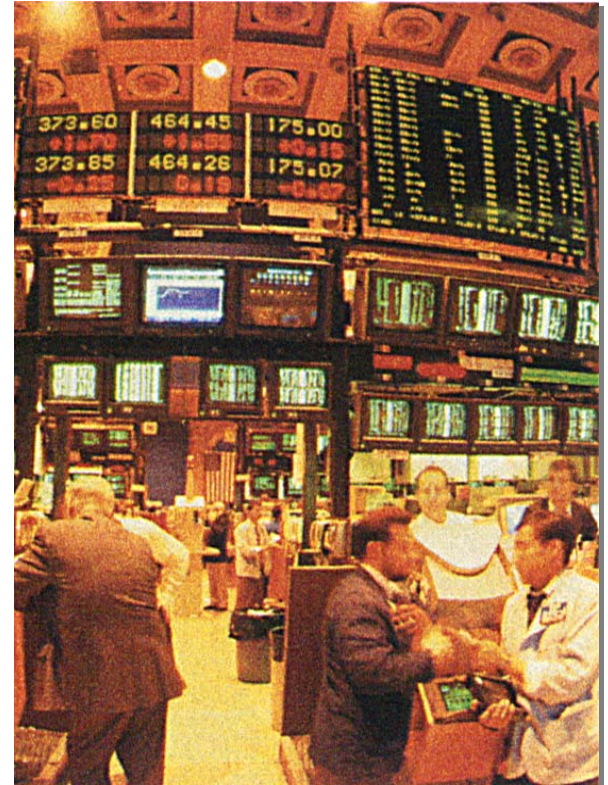
Businesses focused on the highest return on investment are not always in a position to implement new solutions, many of which depend on technologies and fuels that cannot currently compete with the marginal cost of producing a barrel of oil.

Most important of all, the marketplace alone will not act preemptively to mitigate the enormous damage that would be inflicted by a sudden, serious and sustained price increase”

Fred Smith, FedEx

General P. Kelley (Ret)

Energy Security Leadership Council



Lowest Cost / Lowest Risk



People and Partnerships: Key to Our Energy Future

■ Scientific Innovation

- Game-changing technologies, materials, and approaches
- Move resources up the value chain
- Minimize footprint, maximize value

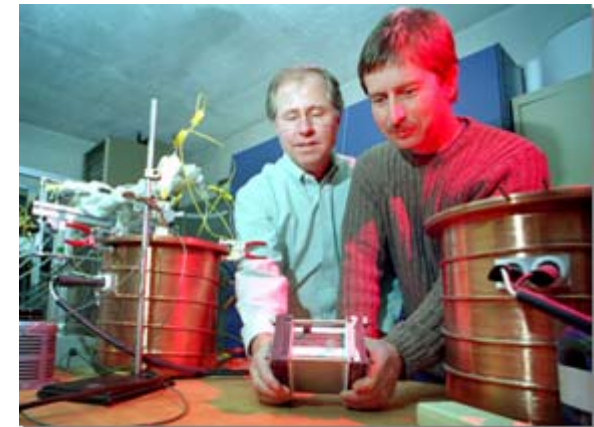
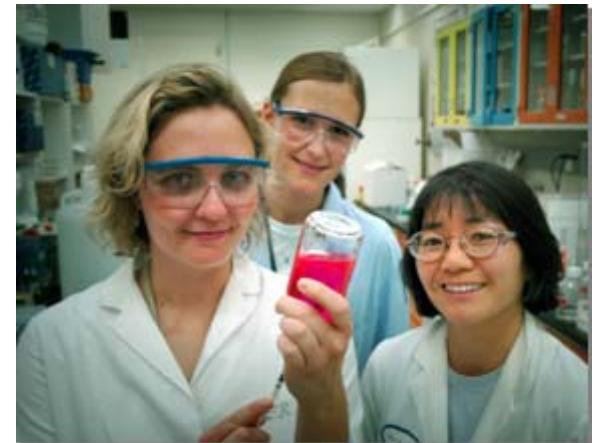
■ Risk Reduction

- Risk reduction through confidence in systems as-built: Does it really work? How well?
- Speed technology to market

■ Informed Policy

- Options, risks, costs, implication chain, etc

Create Opportunity for Markets to Succeed





Technology Leadership

■ Technology R&D is Key

- \$45 trillion global economy, \$3 trillion for energy, 0.03% Energy R&D

■ EPRI Study

- Reduce GHG emissions (electrical generation sector) by 50% by 2050
- \$1.8 trillion cost -- Reduce this by 75% through advanced technology and informed timing of targets

■ Oil Sands Development -- Strategic RD&D Leading Market

■ Objective:

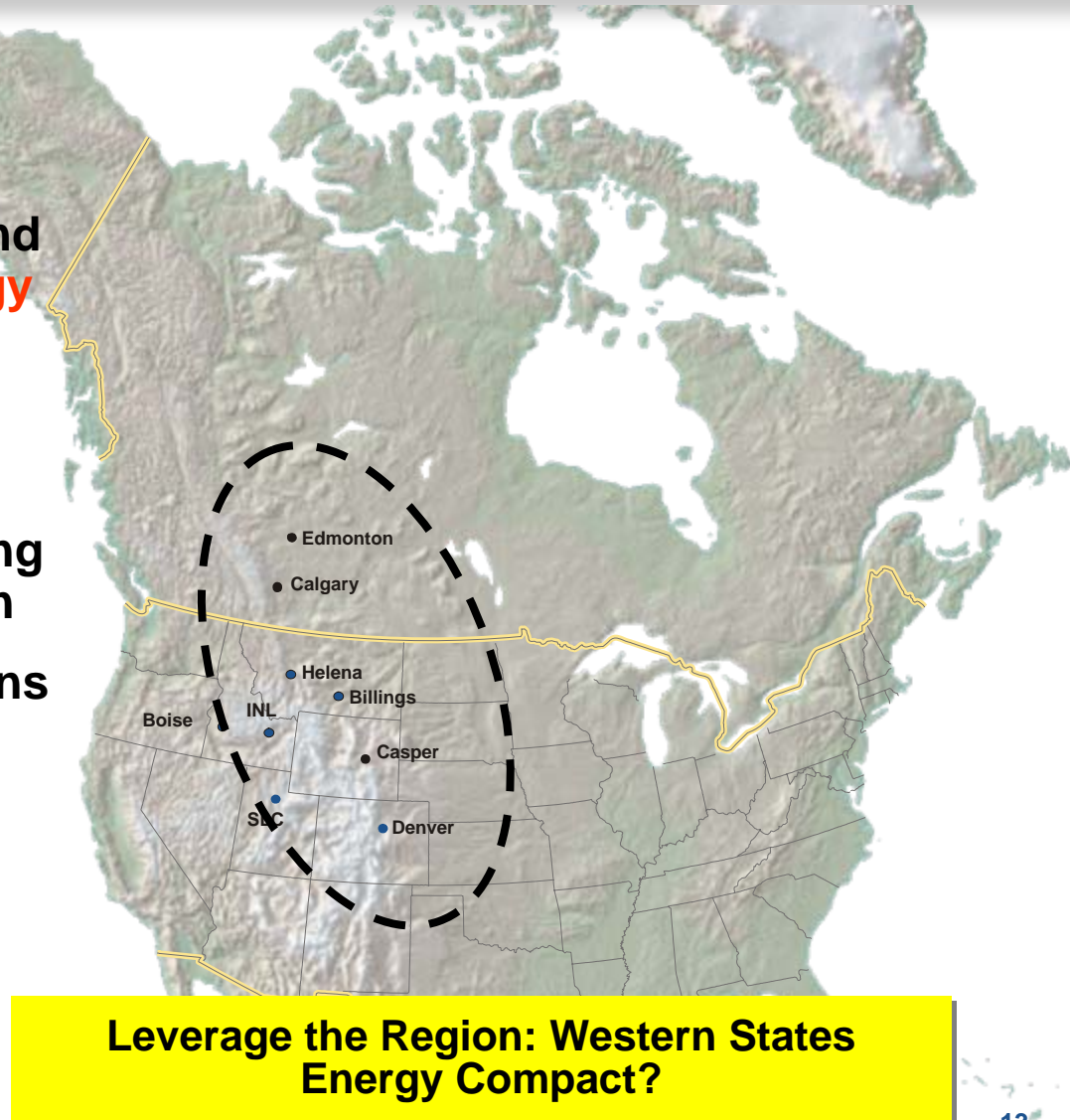
- Create policy construct to enable simultaneous paradigm shift and business development
- Make the most of the regions intellectual and natural resources

Regional RD&D Leadership = Opportunity



Energy Integration on a Regional Scale

- **Rocky Mountain Energy Corridor**
 - world-class conventional and unconventional **fossil energy reserves**
 - significant **renewable resources**
 - energy **infrastructure** offering opportunities for integration
 - People and RD&D Institutions
- **Partnership for Carbon Management** offers region ability to move up the value chain, building regional industry



Leverage the Region: Western States Energy Compact?

A satellite image of the Earth from space, showing the continents of North America, South America, Africa, Europe, and Asia. The image is centered on the Atlantic Ocean, with the Americas on the left and the rest of the world on the right. The colors are naturalistic, with green for land and blue for water. The top of the image shows the Arctic region with white ice.

The Future is Ours to Choose